

## Reaction Time in the Cold

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As reported by Forlano (3) and by Teichner (7) studies of the effects of cold environments on the simple reaction time (RT) suggest that RT is not affected by low ambient temperatures down to  $-50^{\circ}$  F. However, temperature is only one of the factors which make up cold environments. The cooling power of air actually depends on both its temperature and speed of movement (wind-speed). The effect of each of these, singly and in combination, must be studied before safe generalizations can be made about the effect of the cold on RT. Further, the combined action of temperature and wind (windchill<sup>2</sup>) in determining the cooling rate of exposed bodies has been formulated quantitatively; thus, there is a basis for a rational approach to the combined effects problem. It was the concern of the present investigation, therefore, to study the effects of the cold on RT through variation of all three physical factors.

As long as Ss wear protective clothing, as they have in previous studies, S-R relationships may be misleading. That is, with no information beyond the stimulus conditions and S's response, it is not possible to determine whether the environment was actually effective in cooling the body. Failure to find a temperature effect in previous studies may have been the result of lack of actual body cooling. Thus, studies which fail to measure

body cooling cannot yield information of general value nor are the results amenable to theoretical considerations, either physiological or psychological. The present study was designed, therefore, to obtain body surface temperatures for relationship to the effects of cold environments.

### Method

Six hundred and forty infantrymen from Fort Devens were used as Ss. 20-man groups were used, one per day until the total number was exhausted. On arrival at the laboratory the 20 Ss were randomly sorted into five-man subgroups and each operation of the investigation was phased to handle the sequential appearance of the four subgroups. Two subgroups were studied before the noon meal and two after it. Twenty Ss were eliminated for medical reasons prior to starting.

Ss were taken to a dressing room ( $55-60^{\circ}$  F.) which interconnected with the climatic chamber, where they undressed, a multi-point thermocouple harness was put on them and they were dressed in appropriate clothing. These procedures were performed "by the numbers" so that all five Ss were dressed at the same time, thus avoiding individual overheating. While Ss were in the dressing room standard instructions were read to them which explained the details of the procedure to follow. When dressed, they were taken into the climatic chamber which was pre-set for the appropriate environmental conditions.

In the chamber, the five Ss sat side by side about three ft. apart, before a long table in front of a large observation window. They faced sideways to the direction of air movement and were in front view of technicians operating the equipment outside of the chamber. From their positions, however, Ss were unable to observe the operation of the equipment.

Ss sat quietly and cooled for the first 25 min. During this time the instructions were read again and procedures demonstrated. After this they performed on a manual dexterity task for about 20 min. On completion of this task (45 min. of exposure), Ss were seated and 25 successive RTs were obtained. This procedure was completed in 7-10 min. Following this, Ss ran in place slowly for three min. (mild exercise), performed five min. more on the psychomotor task and then 10 more successive RTs were obtained.

Each S was provided with a Morse key fastened to the table. At a verbal ready signal, Ss closed the

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<sup>2</sup> Windchill is a measure of that part of the total cooling of a body due to the action of wind. The term is not usually applied to temperatures above freezing. Values of windchill used in this study were obtained from reference (6) based on Siple and Passel's (5) formula:

$$K_o = (\sqrt{wv} + 100 + 10.45 - wv) (33 - T)$$

where:

$K_o$  = Total cooling in kilogram calories per square meter per hour,

$wv$  = Wind velocity in meters per second,

$T_a$  = Air temperature in degrees centigrade.

keys with their preferred hands. At the reaction signal which was provided by 100 w. lights mounted opposite them, they removed their hands from the keys as quickly as possible and rested them on the table. Standard Electric Timers provided a .01 sec. recording of the times between the simultaneous closing of each of the five simple circuits (onset of lights) and the individual reopening of each circuit as the Morse keys were released.

Ten thirty gauge copper-constantan thermocouples were taped to different parts of the body of each S. The output of each thermocouple was recorded by a Leeds and Northrup recording potentiometer; they were also automatically weighted according to the percentage of total body surface area each represented, integrated electronically and recorded as a measure of mean weighted skin temperature. The ten thermocouple placements and their respective percentage weights are shown in Table 1. In view of the lack of familiarity of the Ss with the situation, it was not deemed advisable to obtain rectal temperatures although these would have been highly desirable.

Table 1

Placement of Thermocouples and Associated Percentage Weights\*

Position	Weight
Instep	.050
Calf	.150
Lat. thigh	.125
Med. thigh	.125
Back	.125
Chest	.125
Upper arm	.070
Lower arm	.070
Hand	.060
Cheek	.100

\* Mean Weighted Skin Temperature =  $\sum \frac{10}{1} (\text{Position} \times \text{Weight})$ .

The output of the thermocouples was recorded in sequence at a rate which provided a complete description of each S's skin temperature once every four min. In addition, the output of an electronic analog-to-digital computer<sup>3</sup> working off the armature of the potentiometer was fed to a No. 523 IBM Summary Punch. Thus, the skin temperatures were immediately available for IBM processing. The potentiometer recordings were used as a means of observing the skin temperatures of the Ss. The Ss were removed from the experiment as soon as possible after an extremity dropped to 38° F.

The experimental plan called for a 2 × 5 factorial of temperature and windspeed, a number of temperatures at constant windspeed and two groups of

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Ss at 60° F., one lightly clothed (fatigues) and one group nude (shorts and socks). Other than these two groups, all other Ss wore a complete standard Arctic uniform. Difficulties in keeping Ss safely above frostbite level at the higher windchills required some modifications in experimental plans. The actual conditions used and the numbers of Ss who started and finished are shown in Table 2.

### Results

Data were used only from Ss who completed the experiment. Each RT was transformed to its reciprocal and all results were treated in terms of the transformed measure. Since this was a reciprocal of time, it may be thought of as an index of speed of reaction and will be called reaction speed (RS). Inspection of successive reactions in each group did not suggest any trend within the reaction series, either one suggesting performance increments or decrements. For this reason the mean RS was obtained for each S for the 25 responses in the first series. These values were used as the basis for determining all effects.

A plot of RS vs. ambient temperature at constant windspeed of five mph showed very little variation among the mean values. An analysis of variance of the temperature effect based on these data yielded an *F* ratio of less than 1.00 which confirms the conclusion that these temperatures had no significant effect.

An analysis of variance of the 2 × 4 factorial represented by temperatures of -15° F. and -35° F. at windspeeds of 5, 10, 15, and 20 mph is presented in Table 3. The unequal frequencies of this factorial were treated as described by Rao (4); the summary table also follows Rao. Evaluation of the wind-temperature interaction mean square provided by Table 3 indicates that these two factors did not interact significantly in their effects. An *F* of 12.21 was obtained for the temperature effect and of 4.88 for the wind effect. Both of these are significant at less than the .01 level of risk. Thus, it may be concluded that both the temperatures and the winds involved in this analysis had significant, independent effects on RS.

When the results summarized in Table 3 are considered along with the finding of no temperature effect at the 5 mph windspeed,

Table 2

Experimental Conditions

Ambient Temperature (° F)	Windspeed (mph)	Wind chill (Kg. Cal./m. <sup>2</sup> /hr.)	No. Subjects		Clothing Conditions
			Start	Finish	
60	5		59	59	Fatigues
60	5		118	118	Nude
30	5	780	100	100	Arctic
0	5	1,166	40	40	Arctic
-15	5	1,359	39	39	Arctic
-15	10	1,609	40	40	Arctic
-15	15	1,765	38	37	Arctic
-15	20	1,873	40	27	Arctic
-15	30	2,018	18	3	Arctic
-25	5	1,438	17	17	Arctic
-35	5	1,617	20	19	Arctic
-35	10	1,914	19	19	Arctic
-35	15	2,100	37	25	Arctic
-35	20	2,288	35	12	Arctic

an interaction of wind and temperature is suggested, but it is one which is not statistically testable in the present experiment. To examine this possibility further, Fig. 1 was prepared. This figure shows the effects of windspeed at -15° F. and -35° F.; it presents the mean values for the present data upon which the analysis of Table 3 was based, and, in addition, it presents the result obtained with the 30 mph wind at -15° F. Inspection of this figure reveals that the differences between the effects of the two temperatures were large except at 5 mph where it is known that the indicated difference is not reliable. Both trends show decreasing RS with increasing windspeed, the curve for -35° F. drop-

ping more rapidly. However, this trend appears to flatten off or actually rise a little after the initial large drop. This, as well as the fact that the other trend appears somewhat positively accelerated, does suggest an interaction of temperature and wind. However, as noted, no interaction is demonstrable.

Figure 2 presents pre- and postexercise mean RS as a function of windchill and also presents the mean values for the two 60° F. groups. It can be seen that the RS was slightly, but consistently greater following exercise than before it. Both trends shown in this figure exhibit a decrease in RS with increasing windchill. The lowest windchill result shown, 780 Kg.Cal./m.<sup>2</sup>/hr., may be

Table 3  
Analysis of Variance of Ambient Temperature and Windspeed Effects

Source	df	Sum of Squares	Mean Square	Mean Square	Sum of Squares	df	Source
Wind ignoring temperature	3	8.22	2.74	5.58	5.58	1	Temperature ignoring wind
Interaction	3	1.51	.50				
Temperature	1	6.72	6.72*	2.68*	8.03	3	Wind
Between cells	7	15.11					
Within cells	210	116.08	.55				
Total	217	131.19					

\* *p* < .01.

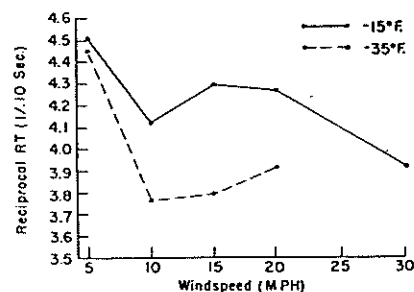


FIG. 1. Effects of windspeed on reaction speed.

suspected of not representing an effect clearly relatable to windchill. This group wore the arctic clothing in a relatively mild condition and there is some possibility, therefore, that the result obtained was due at least partly to a heat stress rather than anything that might be called cold. Support for this possibility may be found in Table 4 which presents the mean skin temperatures during the reaction series and which shows that this group was the warmest of all groups. For this reason, it does not seem safe to include the result obtained with this group in the general windchill trend. Figure 2 also shows that there was no essential difference in RS between the nude and clothed groups at 60° F. before exercise and only a very small difference between them after exercise.

An analysis of variance of the windchill effect shown in Fig. 2, omitting the lowest windchill group, was carried out on the pre-exercise data. This analysis provided an  $F$  of 5.96 which with  $10/364$   $df$  is significant at less than the .01 level. It may be inferred,

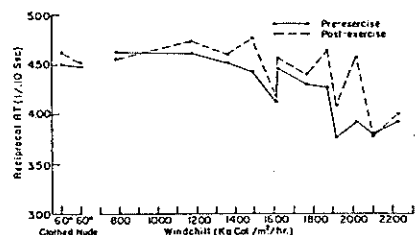


FIG. 2. Effects of windchill on reaction speed.

Table 4  
Mean Weighted Skin Temperature Per Group During Pre-Exercise Series and Correlation with RS

Windchill Kg. Cal./m. <sup>2</sup> /hr.	N*	Mean Temperature ° F	$r_{xy}$
780	56	90.85	.035
1,166	29	87.92	.086
1,359	32	86.62	-.005
1,488	14	85.78	.125
1,609	20	85.50	-.199
1,617	12	84.98	-.041
1,765	31	85.74	.306
1,873	18	84.37	.019
1,914	16	83.55	.118
2,100	20	82.76	.305
2,228	10	81.22	-.494
60° F. Clothed	35	86.73	.218
60° F. Nude	66	80.24	.332**

\* Number of subjects on whom complete skin temperature data were recorded during reaction series.

\*\*  $p < .01$ .

therefore, that the decrease in RS with increasing windchill suggested by Fig. 2 represents a nonrandom effect.

Further inspection of the pre-exercise results in Fig. 2, omitting the lowest windchill value, suggests that the relationship between RS and windchill may be closely approximated by a linear function. The least squares fit of such a function is given by Equation 1:

$$RS = 5.59 - .000813W \quad (1)$$

where:

RS = reciprocal RT in sec.

W = windchill in Kg. Cal./m.<sup>2</sup>/hr.

The standard error of fit of Equation 1 is .26. The constant, 5.59, which limits the intercept is equivalent to an RT of .18 sec. which is in good accord with the magnitude of visual RT to be expected under ideal conditions. Thus, the equation, though approximate, appears to have a reliability and validity of value for practical approximation purposes.

Skin temperatures were available for all Ss but due to the scanning procedure described,

mean values were available for only 359 Ss during the first reaction series and a very small number of Ss during the second series. The mean weighted skin temperature of each group and the number of Ss on which the mean was based are shown in Table 4. It may be seen that the range of the group means was relatively small, and that skin temperature decreased, in general, with increased windchill. It can also be seen that the nude men as a group had the lowest skin temperatures of all.

In order to study the possible relationship of RS to skin temperature, Pearson correlations were computed for each of the conditions of Table 4. The results are also shown in Table 4. All of the coefficients obtained were low and only one was significant in a probability sense. Assuming that all 13 coefficients are estimates of a zero correlation we may ask of the probability of obtaining one significantly different from zero at the .01 level. This probability is .12 which is too high for rejection of the hypothesis. Thus, the correlation among the nude men cannot be accepted with confidence. In addition to the correlations shown in Table 4, a correlation was computed based on all 359 Ss. A coefficient of .18 was obtained which is significant at the .01 level. However, the significance of this correlation is presumably related to the significance of the correlation obtained with the nude men and, therefore, it cannot be accepted with any confidence.

### Discussion

The results are biased in the sense that an increasing percentage of individuals susceptible to frostbite were removed from the experiment as the conditions became more severe. Nevertheless, a clear and systematic impairment of performance was demonstrated, an impairment that could not have been less and would probably have been greater had these Ss not been removed. A further qualification must be made, that all conclusions apply to "unacclimatized" men, within about 75 min. of exposure, not suffering physiological distress. With these qualifications the results indicate that RT is not affected by low ambient temperature, at least down to -35°

F., providing the windspeed does not exceed about five mph. On the basis of previous conclusions (3, 7), the lower limiting temperature at low windspeed may be inferred to be less than this, at least -50° F. On the other hand, for windspeeds of 10 mph and greater, RS decreases with decreased temperature at least from -15° F. and below. It was also shown that windspeed has a marked effect on RS at least at temperatures of -15° F. and below. Finally, it was demonstrated that RS decreases systematically with increases in windchill.

Equation 1 provides a first working formula for application to the design of equipment and clothing and to the use of men for cold-weather conditions. Although it is limited to unacclimatized, selected men, and undoubtedly subject to variation with changes in clothing, shelter, and the physiological conditions of individuals, the results suggest that the RS function is not importantly based upon physiological changes of the individual with cold exposure. At least, the lack of correlation of skin temperatures and, by inference, rectal temperatures (1), with observed RS differences suggests that the function obtained was due to other than body heat losses.

One plausible explanation of the results may be called the distraction hypothesis. This hypothesis assumes that other aspects of the environment (wind-produced noise, discomfort, and the perceived threat of cold exposure) provide competing stimuli which interfere with the response elicited by the reaction signal and thus produce increased latencies. The presence of such competing stimuli should be most critical during the foreperiod of reaction, and, therefore, relatable in a measurable way to the presence of nonoptimum preparatory muscular phenomena (2, 8).

A distraction hypothesis has interesting implications. The elicitation strength of distracting environmental stimuli should depend on their intensity, frequency and duration of previous occurrences, conditions of reinforcement during these occurrences and the anxiety level of the individual; in short, on conditions of learning. This hypothesis also sug-

gests that so-called acclimatized individuals, short of marked physiological changes, may be individuals who are habituated in a psychological sense rather than acclimated in a physiological sense. Thus, it may be possible to speak not only of a *physiological cold tolerance*, a term which refers to the resistance of the individual to the cooling power of the environment, but also to a *psychological cold tolerance* and mean by this resistance of the individual to the distracting power of the environment. The former presumably depends upon physiological (circulatory, thalamic, etc.) and morphological (body fat, surface area and configuration) conditions and characteristics of the individual. The latter presumably depends upon the state of habituation of the individual and his anxiety level.

#### Summary

Visual RT's were elicited from 620 soldiers sorted into 14 different groups representing a variety of ambient temperatures, windspeeds and windchills. Included were two groups at 60° F., five mph, one of which was nude and the other lightly clothed. RT was measured after 45 min. of exposure and again following a short, mild exercise, after 65 min. of exposure. In addition, mean area-weighted skin temperatures were obtained. The following conclusions drawn from the results apply to the effects of the cold on "non-acclimatized" and/or "non-habituated" men, not in physiological distress:

1. At low windspeed, at least up to five mph, low ambient temperature has no effect on RS, at least down to -35° F. and probably down to -50° F.

2. At windspeeds of 10 mph and greater, low ambient temperature produces a significant decrease in RS.

3. Windspeed produces a significant decrease in RS.

4. Mild exercise produces a small recovery in RS.

5. If men of low "physiological cold tolerance" are removed from the more severe environmental conditions and if Ss wear protective clothing, RS is essentially a linear decreasing function of windchill.

6. It was hypothesized that the RS function obtained is psychological in nature; a specific hypothesis of "psychological cold tolerance" was proposed.

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